PhysicsFlash
July 2018
Approved for public release; distribution is unlimited.

INSIDE

Exploring beyond the Standard Model

Physics Division researchers advance understanding of the universe with groundbreaking particle physics discoveries

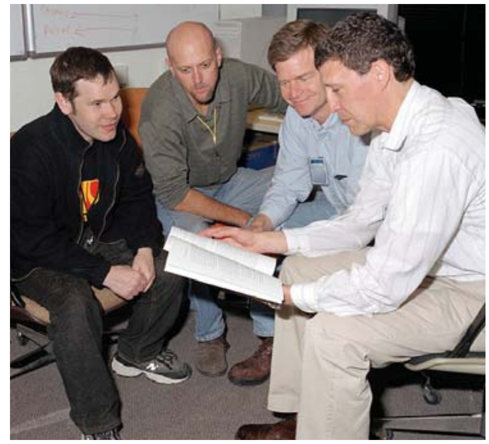
Fundamental nuclear physics research is an essential element of the Laboratory's mission to solve national security challenges through scientific excellence. Basic science research advances the Lab's mission through new discoveries and underpins the Lab's applied research by attracting and developing the required expertise and capabilities.

Physics Division has a distinguished record of contributions to the grand scientific challenge of physics beyond the Standard Model of particle physics. These range from the 1950s research by Frederick Reines and George Cowan that earned Reines the 1995 Nobel Prize in Physics for the detection of neutrinos experimentally to today's work by Physics Division staff and their colleagues who have been in the news recently for their pioneering particle physics research.

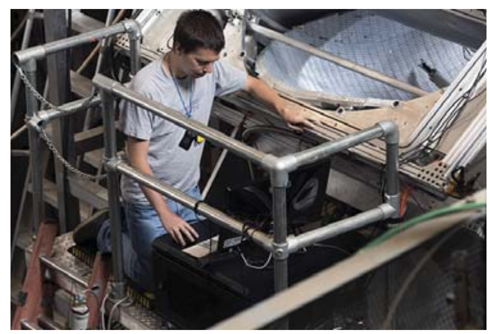
New results by the MiniBooNE collaboration have potentially identified a new elementary particle—a fourth type of neutrino known as a "sterile" neutrino. If found to be a valid result in future experiments, this particle provides challenges for the Standard Model of particle physics. The experiment, conducted by a multi-institutional team co-led by Los Alamos using the MiniBooNE detector at Fermi National Accelerator Laboratory, confirms results found in the 1990s in the Los Alamos Liquid Scintillator Neutrino Detector. The work, "Observation of a significant excess of electron-like events in the MiniBooNE short-baseline neutrino experiment," was presented at the Neutrino 2018 conference in Germany in June.

For the first time, measurements of the neutron lifetime are considered accurate enough that potential corrections are not larger than the uncertainties. The study, done at the Lab's Ultracold Neutron Facility, paves the way for better understanding of how atoms were first created during the Big Bang. The multi-institutional team used the Los Alamos Neutron Science Center's 800-MeV proton beam to liberate bound neutrons and inject them into a magnetic trap and then develop an improved measuring method. The research, the result of some 10 years of work, was published in *Science* as

continued on page 3



MiniBooNE control room: participants from Los Alamos are (left to right) Gordon McGregor, Richard Van de Water, Geoffrey Mills, and Bill Louis.



Ultracold Neutron Facility: Tennessee Technological University physics student Keegan Hoffman prepares to perform magnetic field mapping by removing part of the magnet array with the vacuum vessel end cap.

MAJORANA DEMONSTRATOR: John Wilkerson (left) and Cabot-Ann Christofferson monitor the underground neutrino detector.
CREDIT: Sanford Underground Research Facility

Los Alamos
NATIONAL LABORATORY
EST. 1943

From David's desk . . .

As I said in my Student All Hands Meeting (more later), Physics Division's science answers questions about the nature of the universe and delivers solutions for national security concerns. As described in this issue, the past few months have been very productive in answering questions about the nature of the universe.

The P-25 ultracold neutron team has published the world's most accurate measurement of the lifetime of a free neutron, 877.7 ± 0.7 (stat) +0.3/-0.1 (sys) sec., in *Science*. It is the first high-precision measurement where the corrections due to systematic effects are less than the systematic uncertainties. With the quoted uncertainties, this measurement has a precision of about one part in 1000. This relative lack of precision was one of the surprises that I got when I took this job. I had assumed that all fundamental constants were known to many decades of precision.

The P-25 neutrino team has recently submitted results from the MiniBooNE collaboration that show a significant excess in the observation of electron-like events. This confirms the results from the Los Alamos Liquid Scintillator Detector that were obtained in the 1990s. Taken together, these results are at the $\sim 6\sigma$ level, considered a gold standard in high energy physics. One possible explanation for the observations is the existence of a "sterile" neutrino, a fourth type. Further experiments will be required to determine if this is the correct explanation. These experiments could be carried out with the Captain-Mills detector proposed for LANSCE.

The P-23 neutrino-less double beta decay team (MAJORANA DEMONSTRATOR) has published a new upper limit on the lifetime of ^{76}Ge due to double beta decay. This limit is important because it is used to determine if the neutrino is its own antiparticle. It could help determine why there is more matter than antimatter in the universe.

It is very gratifying to see the progress that is being made in understanding the nature of the universe, and that work is being recognized by the Department of Energy, both by what is put on its website and by its 2018 Early Career Awards. Two Physics Division staff members were just notified that they received these awards. Congratulations to them!

- Cesar da Silva (P-25) for "Gluon saturation search in the deep small Bjorken-x region using the Large Hadron Collider Beauty Experiment (LHCb)," and
- Alex Zylstra (P-24) for "Studying nuclear astrophysics with inertial fusion implosions."

"The students are here, the students are here." I held my All Hands meeting with the students and their mentors on 21 June (see photo below). There are many fresh faces and some returning ones. It is incumbent on all of us to welcome them and ensure that they have a wonderful summer. They represent our future. Treat them with the respect that you expect of your interactions with others.

I hope that everyone has an enjoyable summer with your families and your coworkers. Remember we are under fire restrictions and act accordingly. And for those of us who like being in the mountains, here's hoping that the restrictions are lifted soon. Hope for an early monsoon season!

Physics Division Leader David Meyerhofer

"As described in this issue, the past few months have been very productive in answering questions about the nature of the universe."

David

Exploring cont.

"Measurement of the neutron lifetime using an asymmetric magneto-gravitational trap and in situ detection."

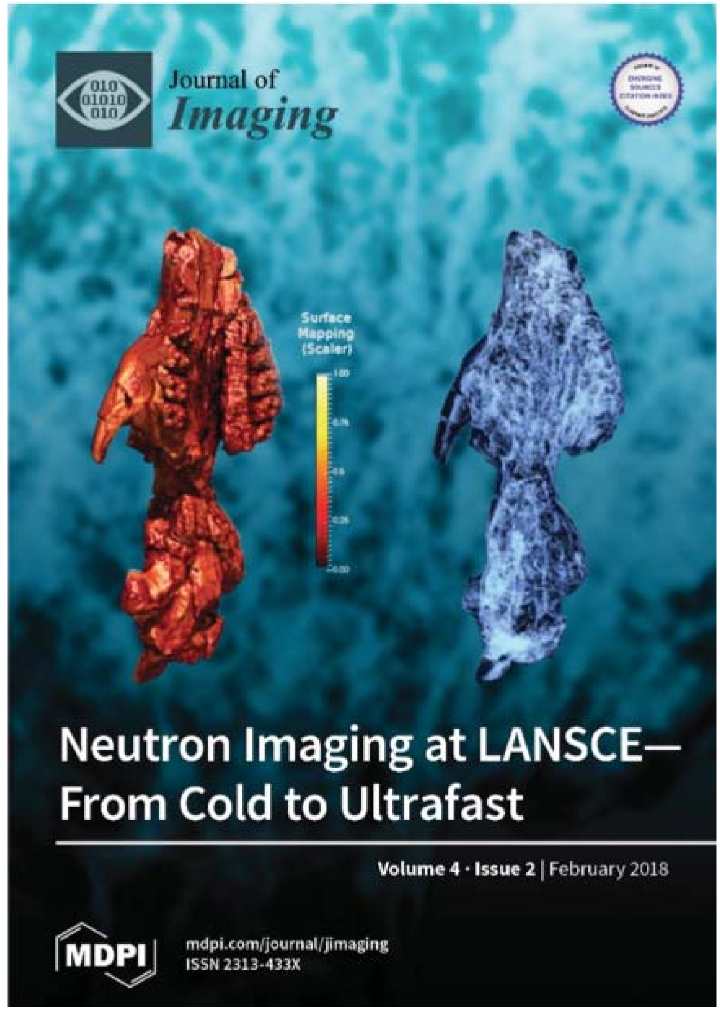
Collaborators on the MAJORANA DEMONSTRATOR, an experiment led by Oak Ridge National Laboratory, have shown they can shield a sensitive, scalable 44-kilogram germanium detector array from background radioactivity. This is a critical accomplishment for the underground neutrino experiment, showing the feasibility of designing a one-ton future experiment that will study the nature of the elusive neutrino and investigate why there is more matter than antimatter in the universe. The work is described in "Search for neutrinoless double-ß decay in ^{76}Ge with the MAJORANA DEMONSTRATOR," in *Physical Review Letters*.

Journal of Imaging features LANSCE neutron imaging on cover

At the Los Alamos Neutron Science Center (LANSCE), state-of-the-art detector technologies are being used with the LANSCE fast-pulsed and intense neutron beams to perform previously unattainable measurements of element- and isotope-specific imaging by gating on specific nuclear resonances. A survey of these advances, applications, and future prospects was featured in a cover article in an issue of *Journal of Imaging* and was part of a special issue on neutron imaging.

In recent years, neutron radiography and tomography have been applied at different beam lines at LANSCE covering a wide neutron energy range. Substantial development of the field of energy-resolved neutron imaging with epithermal neutrons, using neutron absorption resonances for contrast as well as quantitative density measurements, has been done at the Target 1 (Lujan Center) flight path 5 beam line and continues to be refined. Only three facilities worldwide (J-PARC in Japan, ISIS at the Rutherford Appleton Laboratory in England, and LANSCE) have demonstrated the capability to make such measurements. Applications include imaging of metallic and ceramic nuclear fuels, fission gas measurements, tomography of fossils, and studies of dopants in scintillators. The technique provides the ability to characterize materials opaque to thermal neutrons and to utilize neutron resonance analysis codes to quantify isotopes to within 0.1 atom %. The latter also allows measuring fuel enrichment levels or the pressure of fission gas remotely.

More recently, the cold neutron spectrum at the ASTERIX beam line, also located at Target 1, was used to demonstrate phase contrast imaging with pulsed neutrons. This extends the capabilities for imaging of thin and transparent materials at LANSCE. Cold neutrons have been used to study water uptake in plants and to observe small cracks in a variety of materials.



The cover image features thermal neutron and hard x-ray CT scans of part of a skull of *Tetraclaenodon puercensis*, a herbivorous mammal that lived in New Mexico 60-63 million years ago.

In contrast, high energy neutron imaging at LANSCE, using unmoderated fast spallation neutrons from Target 4 (Weapons Neutron Research Facility), has been developed for applications in imaging of dense, thick objects.

For example, an aluminum "chile pepper," iron pyrite crystals, and a pewter trinket were imaged inside a 7.5-cm-thick uranium annular cylinder. Using fast (ns) time-of-flight imaging enables testing and developing imaging at specific, selected MeV neutron energies and testing and characterization of fast scintillators. The 4FP-60R beam line has been reconfigured with increased shielding and new, larger collimation dedicated to fast neutron imaging. Researchers continue to explore ways in which pulsed neutron beams and the time-of-flight method can provide additional benefits.

Reference: "Neutron imaging at LANSCE–from cold to ultrafast," *Journal of Imaging* **4** (2), 45 (2018). Researchers include Ron Nelson (LANSCE Weapons Physics, P-27), Sven Vogel (Materials Science in Radiation and

continued on next page

Neutron imaging cont.

Dynamics Extremes, MST-8), James Hunter (Applied Engineering Technology, AET-6), Erik Watkins (Materials Synthesis and Integrated Devices, MPA-11), Adrian Losko (MST-8), Anton Tremsin (University of California, Berkeley), Nicholas Borges (MST-8, Worcester Polytechnic Institute), Theresa Cutler (Advanced Nuclear Technology, NEN-2), Lee Dickman (Earth System Observations, EES-14), Michelle Espy (AET-6), Cort Gautier (AET-6), Amanda Madden (Space Science and Applications, ISR-1), Jaroslaw Majewski (Center for Integrated Nanotechnologies, MPA-CINT, National Science Foundation), Michael Malone (Applied Modern Physics, P-21), Douglas Mayo (Monte Carlo Codes, XCP-3), Kenneth McClellan (MST-8), David Montgomery (Plasma Physics, P-24), Shea Mosby (P-27), Andrew Nelson (Engineered Materials, MST-7), Kyle Ramos (HE Science and Technology, M-7), Richard Schirato (ISR-1), Katlin Schroeder (University of New Mexico), Sanna Sevanto (EES-14), Alicia Swift (Y-12 National Security Complex), Long Vo (MST-8, Kansas State University), Thomas Williamson (New Mexico Museum of Natural History and Science), and Nicola Winch (NEN-2).

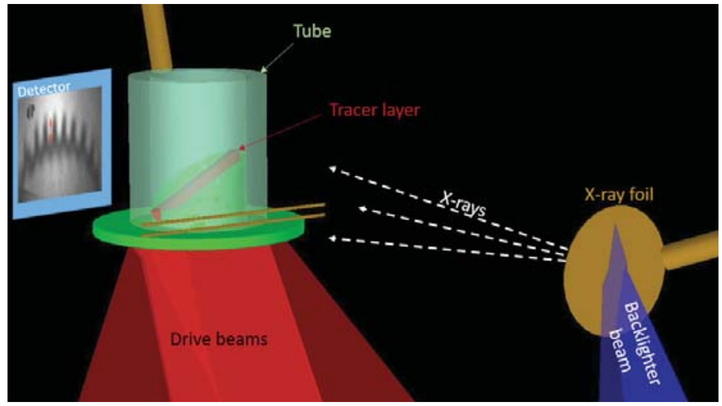
This work was performed under the auspices of the U.S. DOE under Contract No. DE-AC52-06NA25396 and has benefited from use of the LANSCE accelerator facility supported under the same contract. Portions of this work were funded by the U.S. DOE Office of Nuclear Energy, Nuclear Technology Research and Development program, the U.S. DOE National Nuclear Security Administration Nonproliferation Research and Development program (NA-22), the Laboratory Directed Research and Development program of Los Alamos National Laboratory, the New Mexico Consortium, and a LANL PADSTE small-equipment grant.

Technical contacts: Ron Nelson and Sven Vogel

Oblique shocks to a vortex provide insight into fluid instabilities

The fluid instabilities inherent to systems with shocks can result in mixing across interfaces that impacts performance: for example, mixing degrades the yield of inertial confinement fusion (ICF) implosions and strongly impacts the evolution of supernovae. Shocks that interact with perturbed interfaces cause that interface to grow because of misaligned pressure and density gradients that cause vorticity.

In an article published in *Physics of Plasmas*, researchers at Los Alamos and their colleagues examined oblique shocks, i.e., shocks that move at an angle to an interface and shear it, depositing vorticity and creating vortices. To assess this type of shock-interface interaction, the researchers used the University of Rochester's Omega EP (extended performance) laser to conduct experiments on growth in the case of oblique shocks. The results were compared to radiation adaptive grid Eulerian (RAGE) simulations and analytic



Setup of the experiment: drive lasers produce a shock in the experimental package (green). X-rays are produced from the x-ray foil using a separate backlighter laser beam. The x-rays image the tracer layer inside the plastic tube onto a detector, producing an image of the layer under shock evolution.

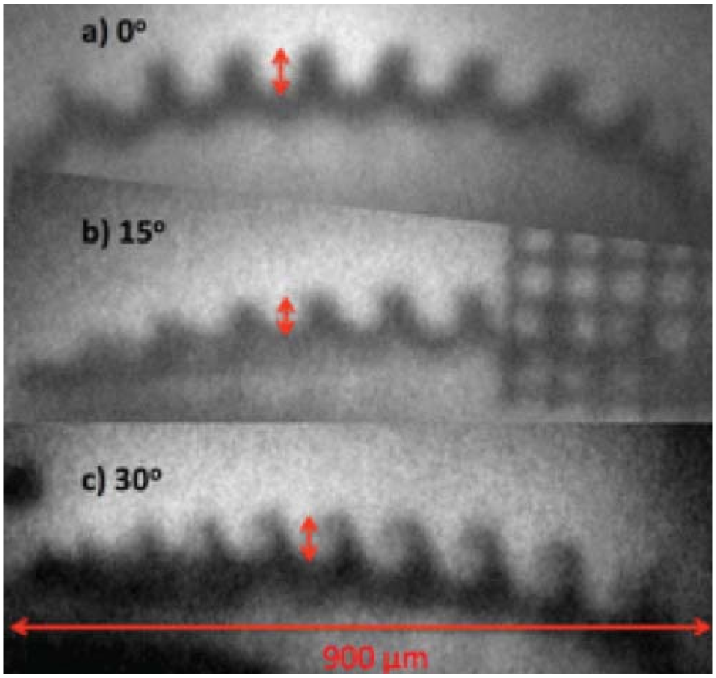
predictions for instability growth. The results contradicted previous theory, instead showing a qualitative mixture of two instabilities called Kelvin-Helmholtz and Richtmyer-Meshkov. The simulations and experiment showed that the interface grew impulsively at early times but showed the spatial structures (whirls) of Kelvin-Helmholtz at late times.

This spurred the development of a new theory: the combination of interface structure and shock-tilt-caused vorticity of only one sign to be deposited on only some portions of the interface. The bunching of the vorticity results in impulsive growth early in time, and as the vorticity is all of one sign, it behaves as the Kelvin-Helmholtz instability late in time. In fact, the early time, impulsive growth rate of the interface was predicted analytically by calculating the amount and distribution of vorticity deposited on the interface. Moving forward, the researchers will utilize the control over vorticity structure to study vortex merger, a dominant process in the late-time, self-similar behavior of Kelvin-Helmholtz.

For these and future experiments, the team is now transitioning to using a new laser RAGE package that better characterizes the laser turn-off rarefaction and more accurately predicts the impact of decompression and deceleration on the interface's late-time growth. Deceleration drives a third instability, the Rayleigh-Taylor instability, which is important to the performance of ICF capsules. The new work will allow the first experimental measurement of coupled Kelvin-Helmholtz and Richtmyer-Meshkov growth in the high-energy-density regime, critical for understanding the impact of low-mode asymmetries in ICF implosions on mixing at interfaces.

This work was funded by the NNSA and DOE Office of Science's Fusion Energy Sciences Joint Program in High-Energy-Density Laboratory Plasmas and was partially supported by the DOE Office of Science Graduate Student Research program. It supports the Laboratory's Stockpile Stewardship mission area and its Nuclear and Particle Futures and Materials for the Future science pillars.

continued on next page



Examples of experimental radiographs taken with a spherical crystal imager after shock breakout of the tracer layer. The shock is incident from the bottom of the images and travels vertically. The top image (a) shows an experiment with no tilt between the shock and interface (Richtmyer-Meshkov, RM). The middle image (b) shows interface evolution with a 15° tilt, still dominated by RM. The bottom image (c) shows an experiment with a 30° tilt between the shock and interface, in which discrete vortex growth dominates. All interfaces have the same, sinusoidal, initial structure. The arrows at each interface roughly indicate the perturbation peak-to-valley, the primary measure of interface growth.

Oblique cont.

Researchers: A.M. Rasmus (Plasma Physics, P-24, and University of Michigan, Ann Arbor); C.A. Di Stefano (XTD-IDA: XTD Integrated Design and Assessment); K.A. Flippo (P-24); F. W. Doss (XTD-IDA); J.L. Kline (AD Weapons Physics, ADX); J.D. Hager (Lockheed-Martin); E.C. Merritt, T.R. Desjardins, and W.C. Wan (P-24); T. Cardenas, D.W. Schmidt, P.M. Donovan, F. Fierro, J.I. Martinez, L.A. Goodwin, and T.E. Quintana (Engineered Materials, MST-7); J.S. Zingale (Santa Fe Institute, New Mexico); and C.C. Kuranz (University of Michigan, Ann Arbor). Reference: "Shock-driven discrete vortex evolution on a high-Atwood number oblique interface," *Physics of Plasmas* **25**, 032119 (2018).

Technical contact: Kirk Flippo

Researchers demonstrate diagnostic potential of transmission high energy electron microscopy

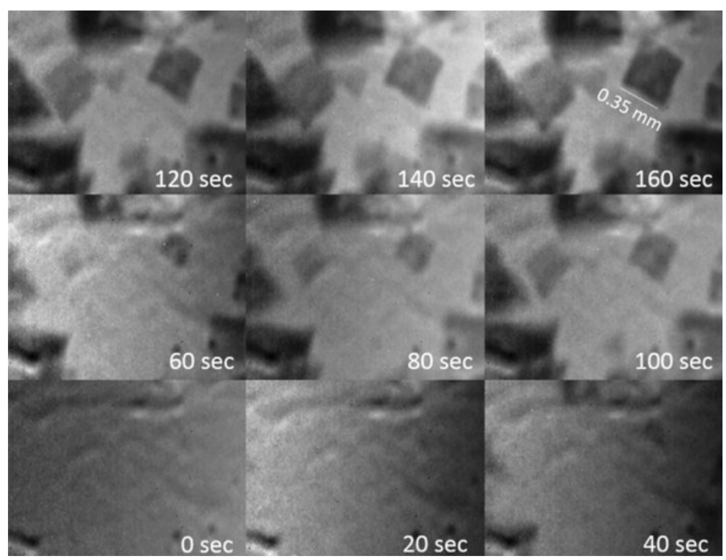
Proton radiography is a well-established technique that uses the penetrating power of high energy protons to generate high resolution measurements of dynamic events. Recognizing this, a team of researchers has investigated the potential of using high energy electrons, like those available at light sources such as the Linac Coherent Light Source, for the study of dynamic systems.

Their technique, transmission high energy electron microscopy (THEEM), provided two additional capabilities to traditional electron microscopy: (1) the ability to image through thicker samples than traditional electron microscopy due to the better penetrating power of high energy electrons than low energy electrons, and (2) fast exposures, down to 1 picosecond, which are ideal for flash radiography of rapidly evolving systems. They demonstrated that electron microscopy, extended to use multi-GeV electron beams, is a remarkable diagnostic probe for studying thin systems with high temporal resolution. These first investigations show that THEEM is capable of providing transmission measurements through objects up to a radiation length thick at MHz frame rates, with equivalently fast camera systems. With 14-GeV electrons, these radiographs have been demonstrated with better than 10-µm resolution; theoretical calculations indicate that 1-µm resolution is achievable.

Using the SLAC National Accelerator Laboratory's End Station Test Beam, the team formed a lens with a magnification of ~11 from four magnetic quadrupoles in a configuration similar to that developed for high energy proton radiography. To investigate the capabilities of the technique, the team conducted investigations with static objects and slow dynamic processes during material processing.

The work is an example of science on the roadmap to MaRIE, the Laboratory's proposed experimental capability for studying matter-radiation interactions in extremes. Materials

continued on next page



The figure shows a set of nine time-stamped frames, showing the formation of faceted bismuth crystals in a bismuth-tin alloy during solidification to study microstructure evolution. These images highlight the potential of THEEM for studies of material processing with a large field of view, which is challenging with other imaging techniques.

HeadsUP!

Use bear-proof dumpsters around the site ... correctly.

Bear-proof dumpsters, purchased by Maintenance and Site Services, are designed to keep bears out, therefore reducing their motivation to come on site for a free meal.

Keep bears out by ensuring that

- both sets of dumpster doors are shut,
- the lock bar is slid fully into place, and
- all carabiners are in place and clipped.

PhysicsFlash

Published by the Experimental Physical Sciences Directorate

To submit news items or for more information, contact Karen Kippen, ADEPS Communications, at 505-606-1822, or adeps-comm@lanl.gov.

For past issues, see www.lanl.gov/orgs/p/flash_files/flash.shtml.

Los Alamos NATIONAL LABORATORY EST.1943

Diagnostic cont.

experiments using MaRIE would demand unprecedented time-resolved imaging capabilities to reveal properties that are important at the “middle” length scale, which may be essential to controlling materials performance. THEEM expands the penetrating power of MaRIE radiography measurements, allowing photons to probe the structure of the dynamic materials with simultaneous THEEM measurements that measure the large-scale hydrodynamics.

The Los Alamos portion of the work was funded by the Laboratory Directed Research and Development program, Director's postdoctoral fellowships, and the DOE Office of Basic Energy Sciences Division of Materials Sciences. The capability supports the Laboratory’s Stockpile Stewardship mission area and the Materials for the Future science pillar by demonstrating measurement capabilities at the mesoscale in material production with prospects for measuring material response under high-energy-density loading conditions relevant to weapons physics and inertial confinement fusion.

Researchers: Frank Merrill (XTD Primary Physics, XTD-PRI); John Goett (Neutron Science and Technology, P-23); John Gibbs (XTD-PRI); Seth Imhoff (Fabrication Manufacturing Science, Sigma-1); Fesseha Mariam, Chris Morris, and Levi Neukirch (Subatomic Physics, P-25); John Perry (Applied Modern Physics, P-21); Daniel Poulson (P-25); Raspberry Simpson and Petr Volegov (P-23); Peter Walstrom (Accelerators and Electrodynamics, AOT-AE); Carl Wilde (P-23); C. Hast, K. Jobe, and T. Smith (SLAC National Accelerator Laboratory); U. Wienands (Argonne National Laboratory); A.J. Clarke (Colorado School of Mines); and D. Tourret (IMDEA Materials Institute, Madrid).

Reference: "Demonstration of transmission high energy electron microscopy," *Applied Physics Letters* **112**, 144103 (2018).

Technical contact: Frank Merrill

Celebrating service

Congratulations to the following Physics Division employees celebrating recent service anniversaries:

Danny Sorenson, P-23	30 years
Jeremy Payton, P-23	20 years
Katherine Prestridge, P-23	20 years
Alexander Saunders, P-25	20 years
John Smith, P-23	20 years
Patricia Smith, P-DO	20 years
Yong Ho Kim, P-24	15 years
Jacqueline Mirabal-Martinez, P-23	15 years
Pulak Nath, P-21	10 years
Amy Tainter, P-25	10 years
Ramon Leeper, P-24	5 years
Benjamin Pederson, P-24	5 years
Theodore Perry, P-24	5 years